Beam-Switchable Phased Array Antennas for the Near-field RFID Applications

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Abstract—This paper presents a new RFID reader antenna design with its radiation beam switchable to track the tags in the near-zone of array aperture. The antenna is realized by using microstrip antenna array with a beam-forming network based on Butler matrix. The radiation of array is focused in the near zone to avoid interferences resulted from the scatterers in the vicinity of antenna. The design approach, numerical simulation and experimental measurement over an antenna prototype are presented to validate the feasibility.

I. INTRODUCTION

There are increasing applications booming in the antenna near-zone communication. Typical examples include, but not limited to, RFID [1], vital life-detection systems [2]-[3], ground penetration radars (GPR) [4],[5] and noncontact microwave detection systems[6-7]. In these applications, the targets under detection are in the near zone of antennas, in which RFID appears to be a representing example. Also in the application scenarios as shown in Fig. 1, the targets may be surrounded by metal scatterers that will cause multipath interferences. In order to enhance the communication quality and system performance, the design of phased array antennas to radiate electromagnetic (EM) fields focused in the near-zone of antenna aperture will be very effective [8]-[10]. In this case, the detection zone is defined so that the EM fields will be focused in this region. The fields scattered from the nearby scatterers outside the target zone will be reduce to avoid interfering the system signals. This paper presents an antenna designs to achieve this goal. Both numerical simulations and experiments will be presented to demonstrate the feasibility.

II. THEORETIC CONCEPT OF ANTENNA DESIGN

An important application scenario of RFID is illustrated in Figure 1(a) [11], which occurs very often in the department stores. The system is consisted of a transportation belt, a RFID reader system, and also the mechanical structures to support the system. Here the commercial products are placed on the transportation belts, and move forward through a detection zone at $d$ measured from the antenna aperture as illustrated in Figure 1(b). The detection zone is defined in a way that the RFID system can read the tag information. The antenna design intends to make the field very strong within this detection and very weak out this zone. Furthermore, the antenna is desired to radiate spot beams which are switched in a sequential order to detect the tag antennas without being interfered by multipath signals. A 2-D array of identical radiating elements with periods, $d_x$ and $d_y$, in the x- and y-dimensions, respectively is considered.

Fig. 1: Application scenario and illustration of a near-field focus problem. The N×M antenna array radiates the focused near fields to provide optimum coverage at a target area. The related position vectors are indicated.

In this design, the systematic configuration of antenna system structure is illustrated in Fig. 2, which consists of three functional blocks to achieve the design goal including the radiation antenna elements, the RF BFN for the radiation fields focused in the near zone in the vertical x-dimension, and the RF BFN with switching beam functionality in the horizontal y-dimension. In particular, the horizontal beam switching circuits (BSC) is consisted of a circuit to realize the DFT relation and another one to compensate the propagation phases for the energy to focus in the near-zone. The DFT relation provides a linear phase variation for the column arrays so that the beam may change the directions with different DFT ports. The frequency band for RFID...
applications at 2.45GHz is adapted, where the wavelength, $\lambda$, in free space is 12.24cm.

Fig. 2: The systematic configuration of switching beam antenna for the near-field focus applications

A. Antenna Elements and Array Arrangement

The antenna elements are designed to radiate left-hand circular polarization (LHCP) fields so that both vertically and horizontally polarized tag antennas can detected in the target area. The microstrip patch antenna is selected, where the LHCP radiation is achieved by trimming the two opposite corners of patch. The antenna array has $8 \times 8$ elements, and is realized on a FR4 substrate ($\varepsilon_r=4.46$ and thickness=1.6 mm). The simulation results of the radiation pattern are shown in Figure 3. The radiation patterns have a gain of 3.17dB. The cross-polarization level is more than 21dB.

B. Beam Forming Circuits for a Near-Field Focused Radiation along the Vertical Dimension

Each column of the array ($\forall m \in [0, M-1]$ and $n=0 \sim N-1$) is treated independently with the same BFN structure to focus the fields at $x=0m$ and $z=1m$. The BFN uses a microstrip transmission line with an open end to generate a standing wave of current distribution. The sinusoidal function of current distribution is then used to control the amplitudes of antenna excitations while the lengths of microstrip lines connected from the microstrip line to the feeds of patch antennas are used to provide the correct phases of excitations. In implementation, the position along the major transmission line corresponding to the desired value of amplitude taper is identified, from where the segmental transmission line is connected to feed the patch with the required phases as governed.

In this case, the amplitude is allowed to be negative as exhibited in the sinusoidal function of standing waves. In addition to the sinusoidal variation, an attenuation of amplitude along the strip line has been observed. The prototype of the antenna array is shown in Figure 4 for a reference purpose.

C. The Realization of Beam Switching along the Horizontal Plane

The horizontal BFN is consisted of a Butler Matrix (BM) to realize the DFT functionality, and a compensation phase to focus the energy in the near zone. In this work, an $8 \times 8$ BM is designed at 2.4GHz as shown in the prototype of Fig. 4. It is noted that the BM provides the linear phase variations in terms of values of DFT operation which is frequency independent. Thus the beam directions are determined by the inter-column period in the x-dimension, which has to be properly selected in order to provide good beam distribution, and avoid grating lobes in the near-zone.

On the other hand, the compensation phase circuits are independent of the BM’s ports, and only a single set is used,
whose major function is to provide an additional freedom of confining the energy in the near zone.

IV. EXPERIMENTAL EXAMINATIONS

The antenna design was first conducted by numerical simulations. After good results have been obtained, the antenna was prototyped as shown in Fig. 4. In this section, the feasibility of antenna design is validated by experimental examinations in the RFID applications at 2.45GHz. Fig. 5 shows the results of field patterns and reading data patterns in the target zone. Firstly they clearly show the field distributions and form spot beams in the target area as shown by the patterns on the left-hand side in Fig. 5. If one defines the coverage area by the -3dB beamwidth contours, the target zone for a spot beam is roughly 0.3×0.15m². The overall coverage is determined by the overlapping of spot beams' -3 and -6dB beamwidth contour as shown in Fig. 5, where the associated ports of spot beams are also marked for reference. The inner six beams provide sufficient coverage for the test area. The outermost two spot beams will result in grating lobes because of the large period (\( d_j = \lambda \)), which can be further suppressed by imposing a larger amplitude taper for the array excitation.

The RFID system used to examine the system performance is made by Syris [13]. The tag is located at 0.9m away from the array aperture. The reading RSSI data is shown on the right-hand side in Fig. 5, where all cases are examined. The maximum values of RSSI reading data are 129 and 125, respectively. It is noted that the uncertain level of the RFID reader’s reading data for the background noise is roughly 105. Thus in Fig. 5, only the values of reading data larger than this threshold are included in the plots. The coverage area justified by the RSSI data is roughly within the area of -12dB contours of radiation patterns. Here it is observed that the RFID reading data confines a smaller area of coverage if it is compared with the radiation patterns in terms of the area defined by the -6dB signal strength.

III. CONCLUSIONS

This paper presents the design of beam-switchable RFID reader antennas. Both numerical and experimental results are examined to validate the feasibility of this approach. Overlapped beam coverage has been demonstrated in this RFID examination. Currently the realization of Butler matrix has a relatively large size because of the implementation using microstrip lines. The future work will attempt to miniaturize the circuits to realize the Butler matrix.

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REFERENCES